



# Mars Rovers: Past, Present, and Future

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AIAA 7/19/01 Dinner Meeting

300 m  
328 yd

# Overview



- Introduction
- Rover past: Sojourner, 1997
- Rovers present: 2003 Mars Exploration Rovers
- New rover technologies at Ames
- Rovers future: 2007 mission and beyond

# Introduction



Why is Mars interesting?

- Most Earth-like planet
- May once have had/still have liquid water and thus life
- May be possible to colonize

NASA's Mars Exploration Strategy:

Follow the water

Water is key because almost everywhere we find water on Earth, we find life.

# Challenges

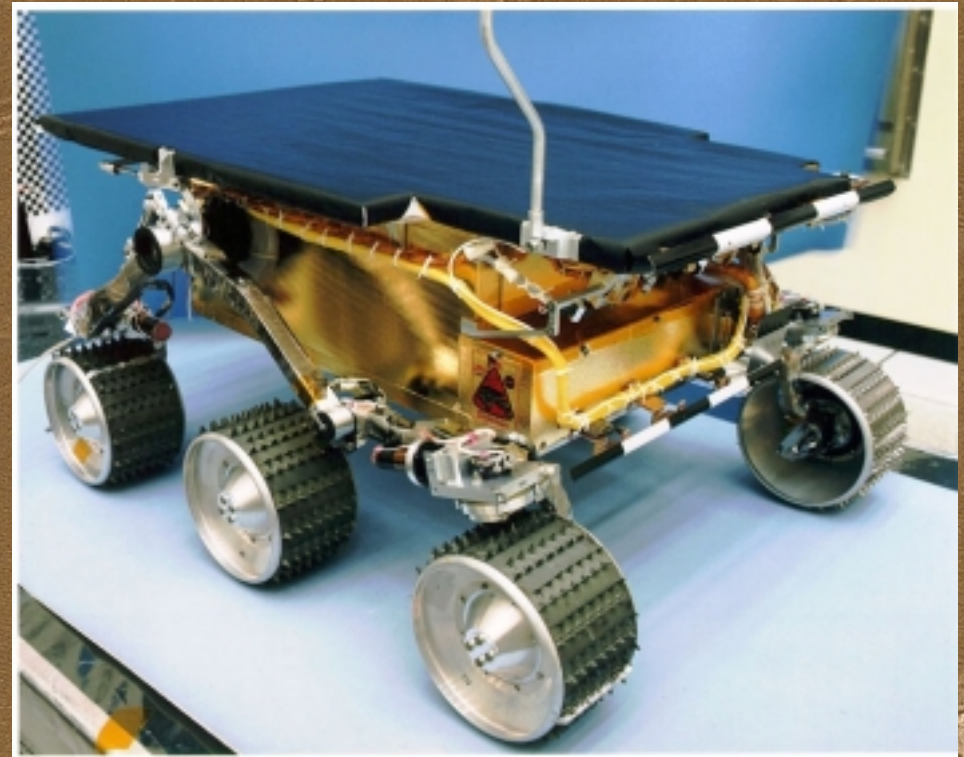


- Communications time delay
- Narrow communications bandwidth
- Extreme temperatures
- Rough, rocky terrain
- No global positioning system
- Dust



# Sojourner Rover Specs

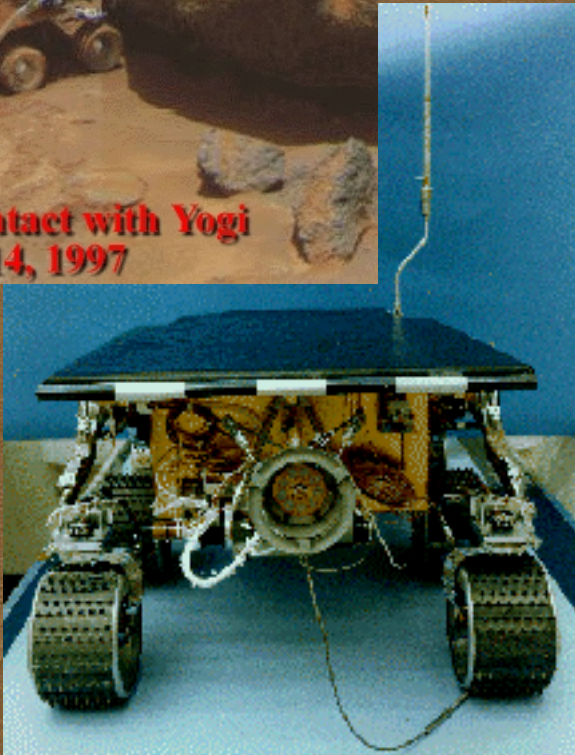
- 13cm (~5in) wheel diameter
- Rocker-bogey chassis
- Top speed: .6m/min
- .22 m<sup>2</sup> solar panel providing peak of 16W
- With batteries, peak available power of 30W
- Normal driving power requirement is 10W
- 80C85 CPU, at 100Kips
- 176K of PROM and 576K of RAM



# Sojourner Instruments

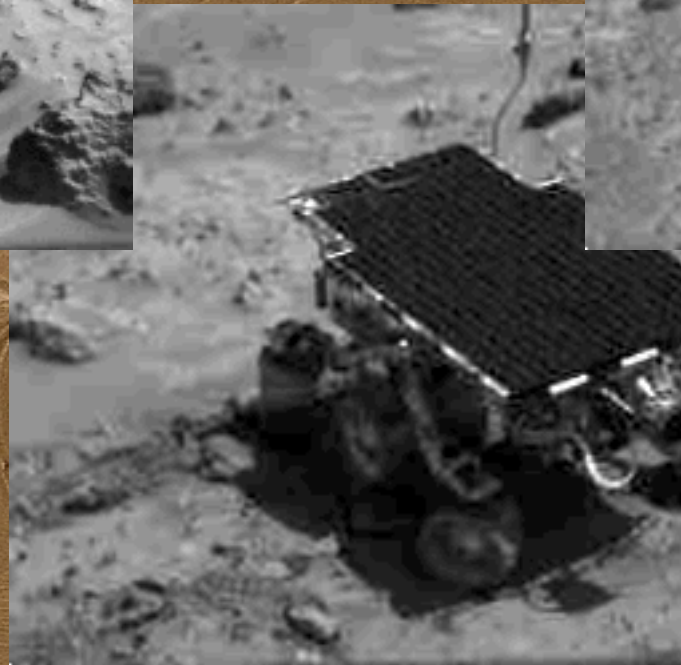


**Sojourner contact with Yogi  
Sol 10 - July 14, 1997**



- Navigational:
  - front viewing stereo pair of cameras
  - laser striping system
  - gyro
  - corrections made using lander imager
- Scientific:
  - Alpha Proton X-Ray Spectrometer (APXS)

# Sojourner Movies



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# Pathfinder Mission Highlights

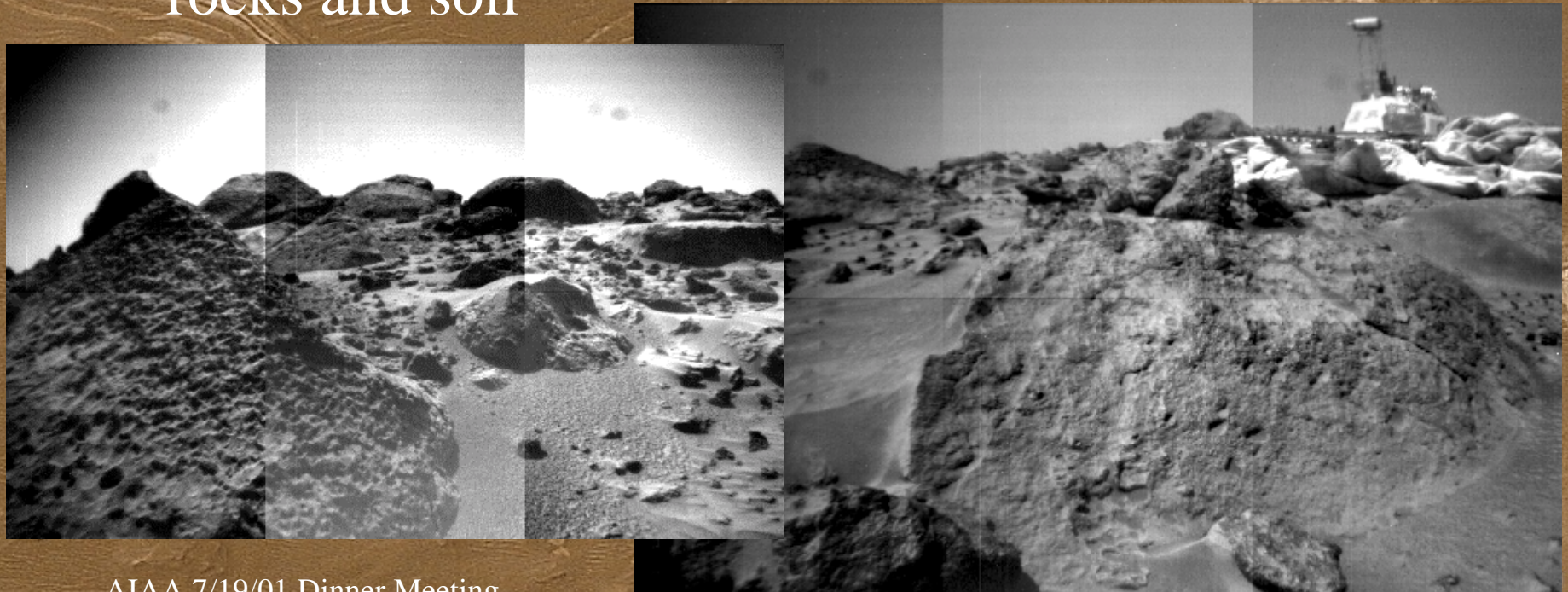


- Launched on December 4, 1996
- 7-month cruise to Mars with 4 trajectory-correction maneuvers
- Landed at 9:57 a.m. PDT on July 4, 1997
  - Bounced at least 15 times up to 12 m high
- Sojourner driven down the ramp on sol 2
- Primary mission: 8 sols
- Total mission: 83 sols

# More Highlights



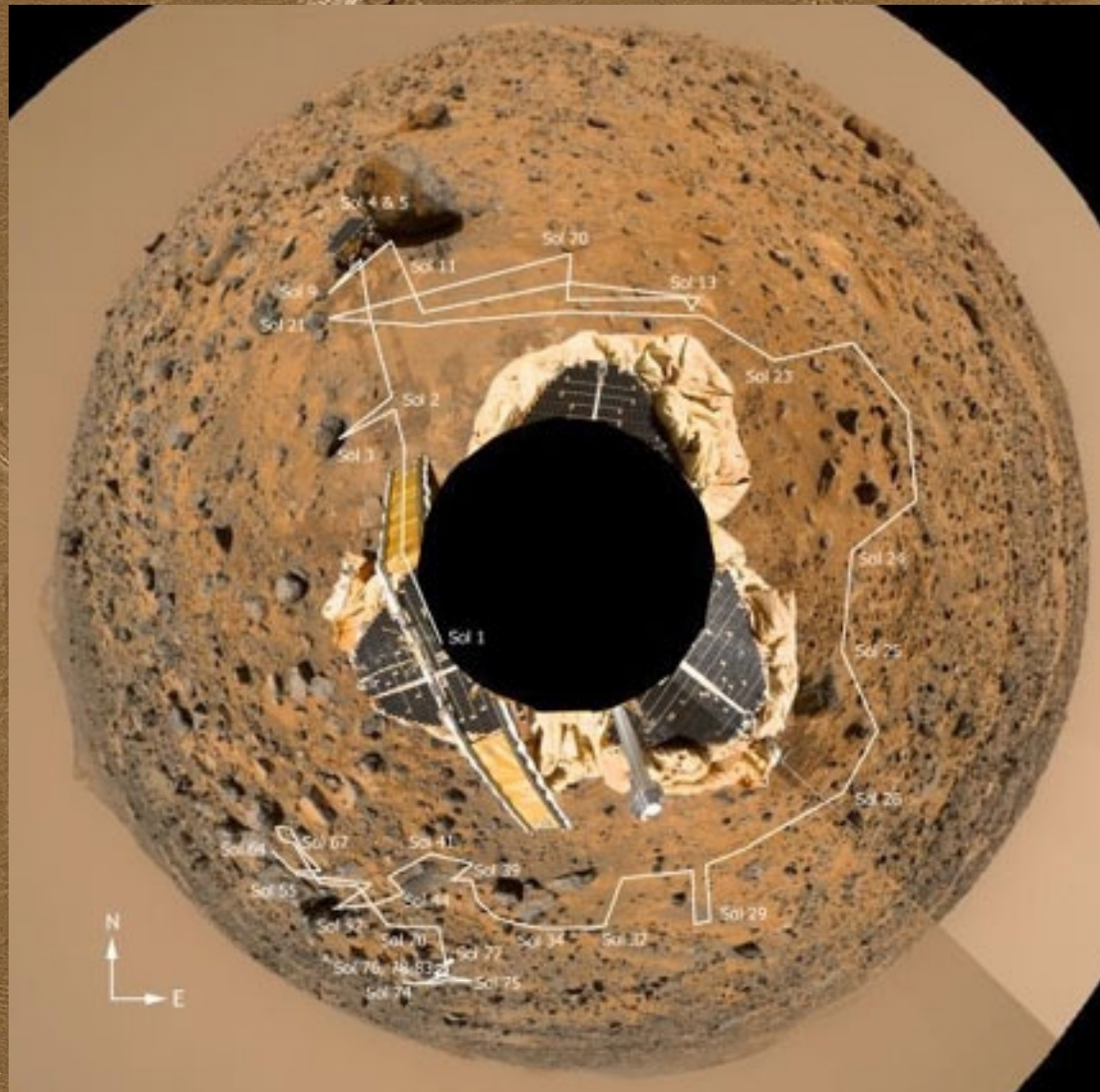
- Sojourner traversed 100m around the lander
- Pathfinder returned over 16,000 lander images and 550 rover images
- Sojourner performed 16 chemical analyses of rocks and soil



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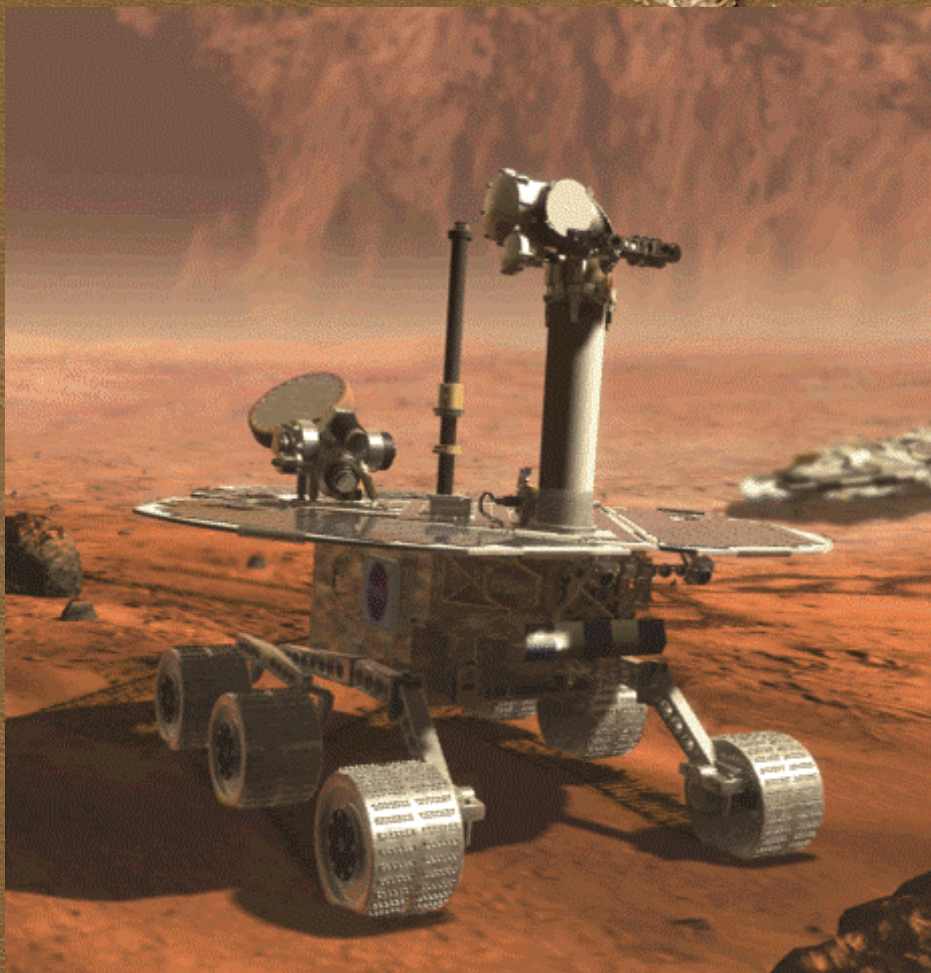
# Mars Sojourner Traverse



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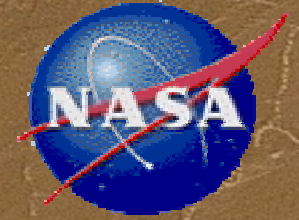
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# 2003 Mars Exploration Rover (MER)



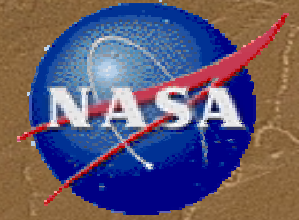
- Size:
  - 1.2 meters high
  - 150 kilograms
- Mobility
  - Top speed: 5 cm/s (.1 mph)
  - Capable of 100 m/day
  - Expected total traverse ~1km
  - Dead lander
  - Communication via orbiter and direct-to-earth (DTE)
- Lifetime
  - Primary mission: 90 sols

# Mast-mounted Instruments



- Pancam
  - Provide high spatial resolution on the morphology of the landing site
- Mini-Thermal Emission Spectrometer (Mini-TES)
  - Obtain mineralogical information for rocks and soils surrounding the rover
  - Capable of detecting silicates, carbonates, sulfates, phosphates, oxides, and hydroxides

# Arm-mounted Instruments



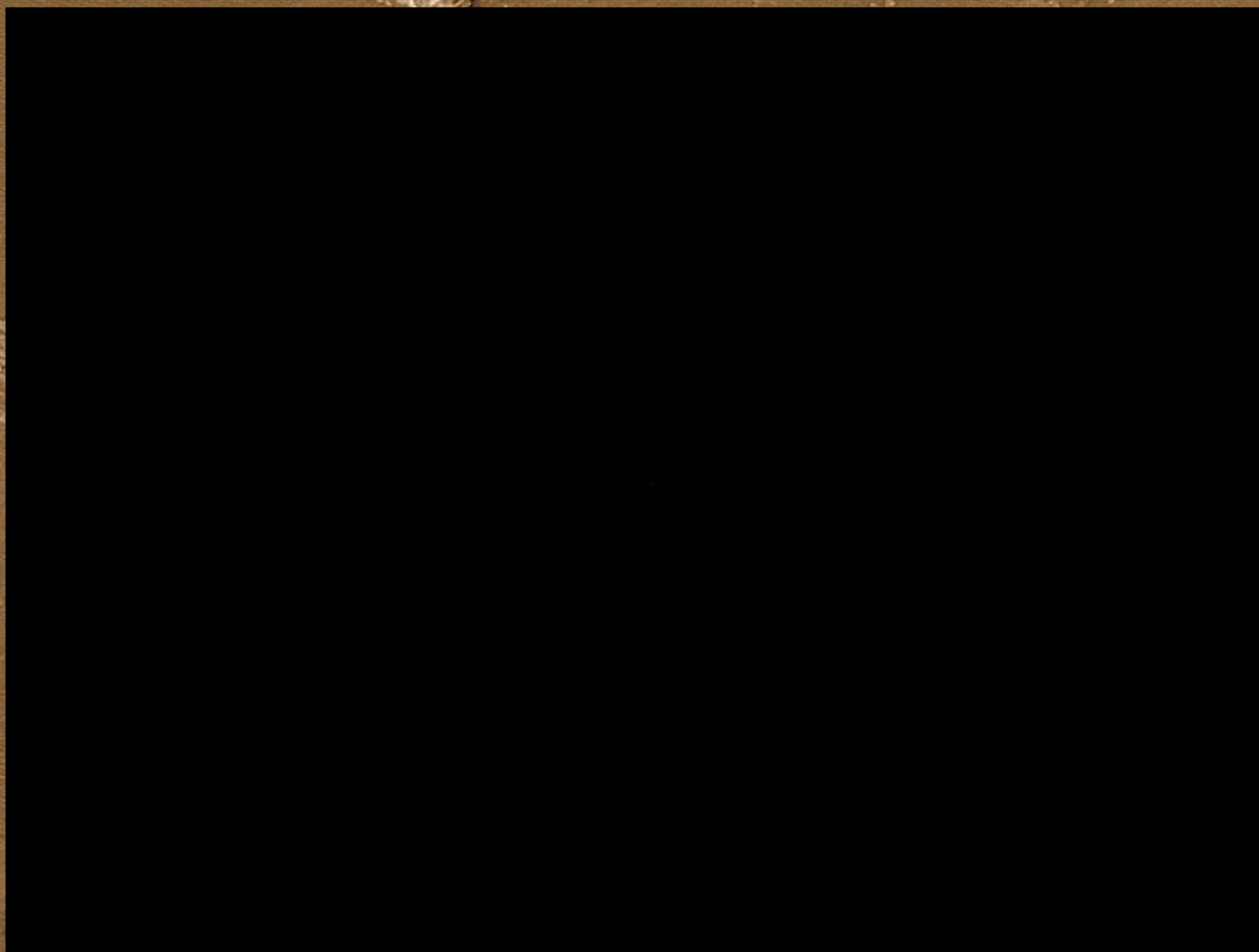
- Rock Abrasion Tool (RAT)
  - Remove surface dust and weathering
- Microscopic Imager
- APXS
- Mössbauer Spectrometer
  - Determine the properties of iron bearing materials

# Navigational Instruments



- Mast-mounted NavCam
- Front and Rear HazCam
- SunCam
  - Sun sensor used to determine global bearing (no compasses on Mars!)
- Inertial Measurement Unit (IMU)

# MER Movie



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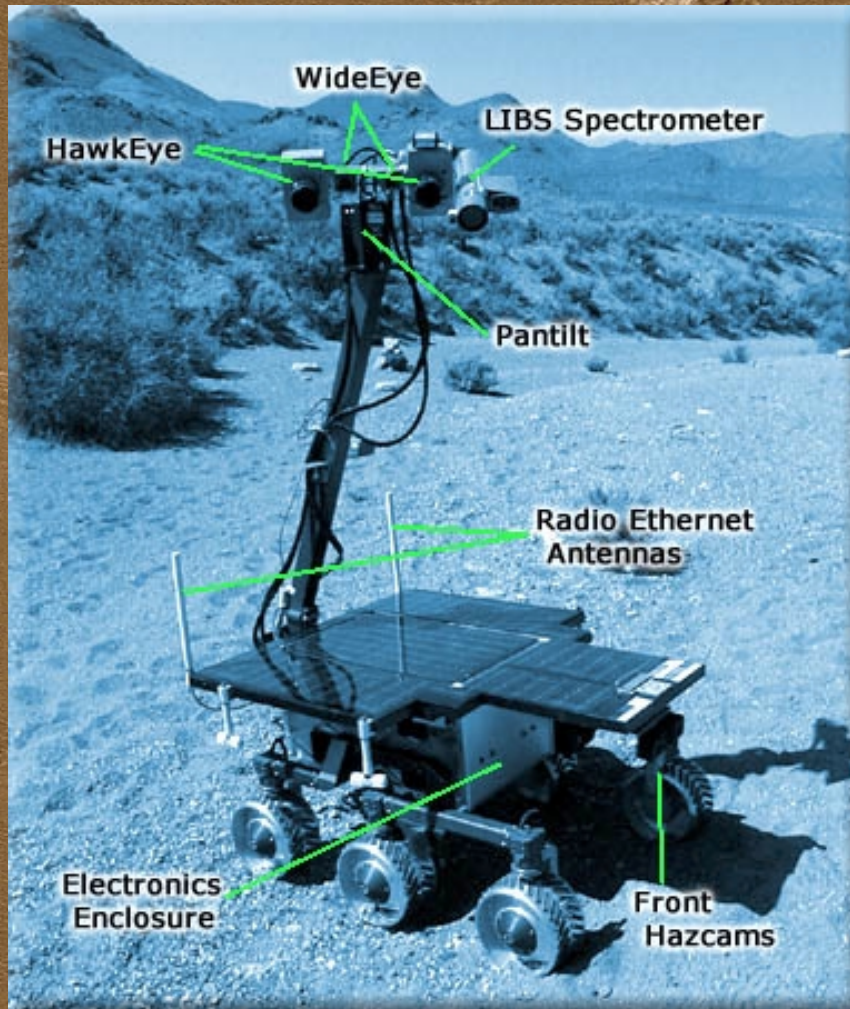
# “Athena” Rover (2003) Prototypes



- Size: (13/7 Sojourner)
  - 1.6 meters high (K9 camera)
- Instruments
  - Athena package analogues
- Used for field testing and development at JPL (FIDO, Rocky8), Ames (K9)

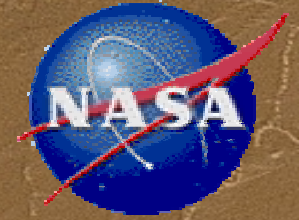


# K9 Rover



- Prototype of Mars rover
- Low power electronics
- Subsystems can be powered on/off
- CPU: 166 MHz mobile Pentium MMX

# K9 Instruments



- High-resolution color cameras
- Near-Infrared Spectrometer
- Raman Spectrometer
- Camera HAnd lens MicroscoPe (CHAMP)



# On-board Science Understanding



- Enables the robot to make decisions based on scientific criteria
- Science understanding modules:
  - Rock detection
  - Layer detection
  - Carbonate detector



# Conditional Plan Execution

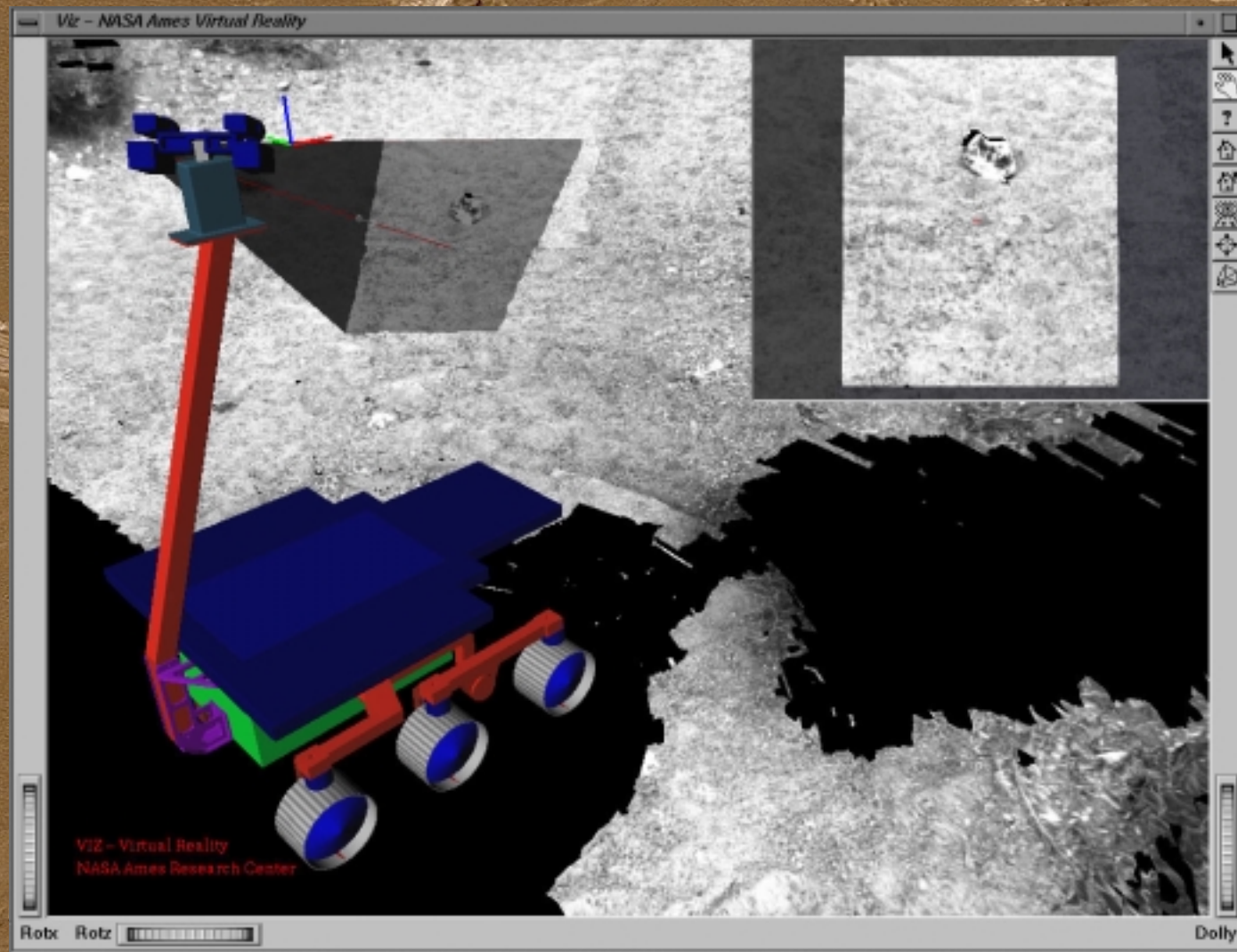
- CRL – Contingent Rover Language
- CX – Conditional Executive
- Flexible, condition-based execution
  - temporal conditions (absolute, relative)
  - resource conditions
  - state-based conditions
  - conditions on any node (high- or low-level)
- Hierarchical structure
  - *task*: executable action
  - *block*: sequence of nodes
  - *branch*: choice point

# Visual Servoing



- Visually tracks a target and drives to it
- Does not require and position information, only needs to know camera parameters and pan and tilt angles

# Viz - visualization tool



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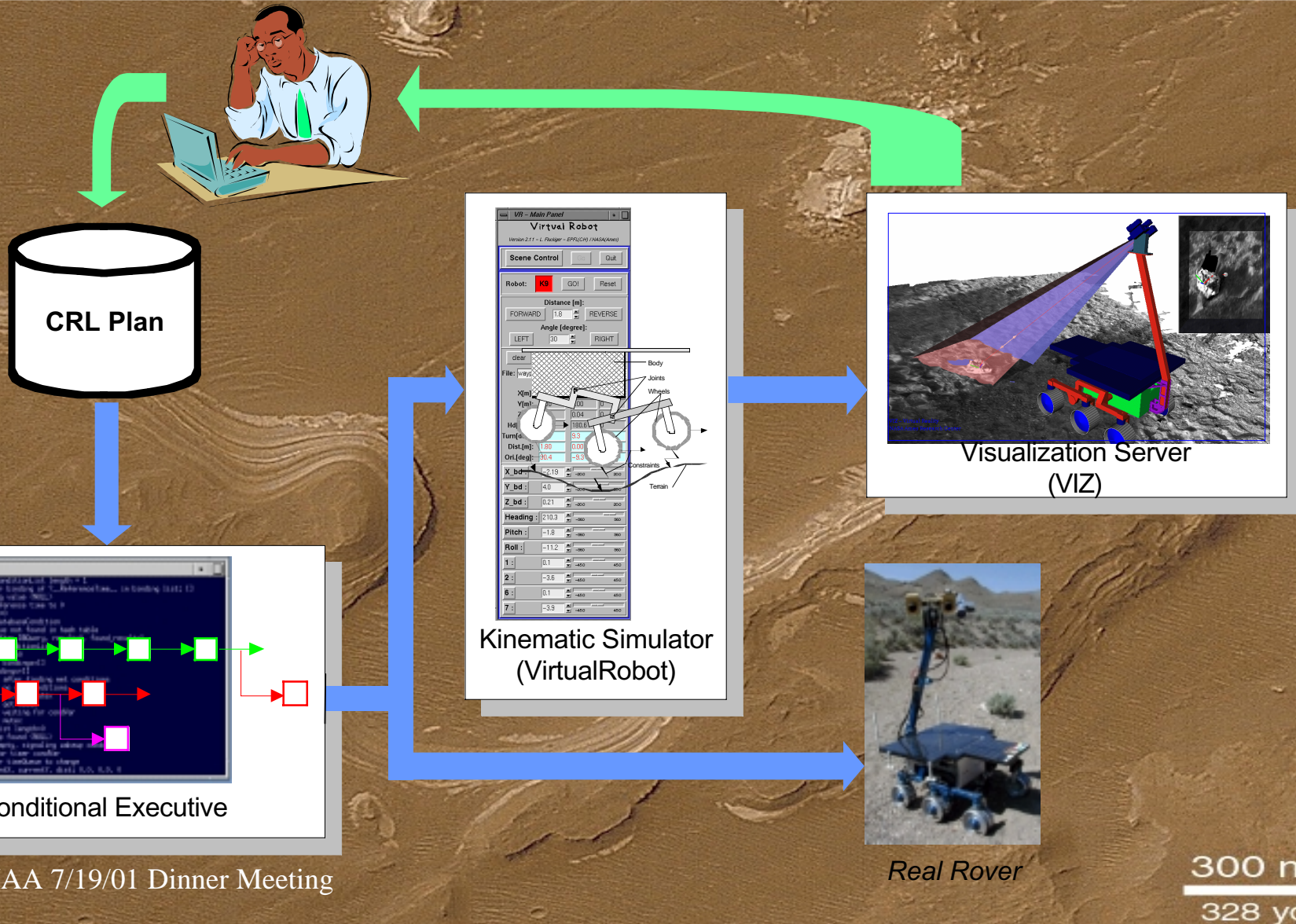
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# Visualization (cont.)



- Stereo pipeline uses rover stereo images to create terrain models
- Viz gives scientists a better understanding of context and scale
- Provides measuring tools and markers
- Valuable tool for science planning using simulator, VirtualRobot
- Can run command sequences through the simulator to verify correctness

# Ground Operations - VIPER



# Field Testing



- Blind field experiments:
  - Deploy a rover in a Mars analogue field site
  - Science team in mission control not told location
  - Given only data returned by the rover, team must characterize the site
- Test and demonstrate autonomy technologies and operation scenarios
- Train science team members

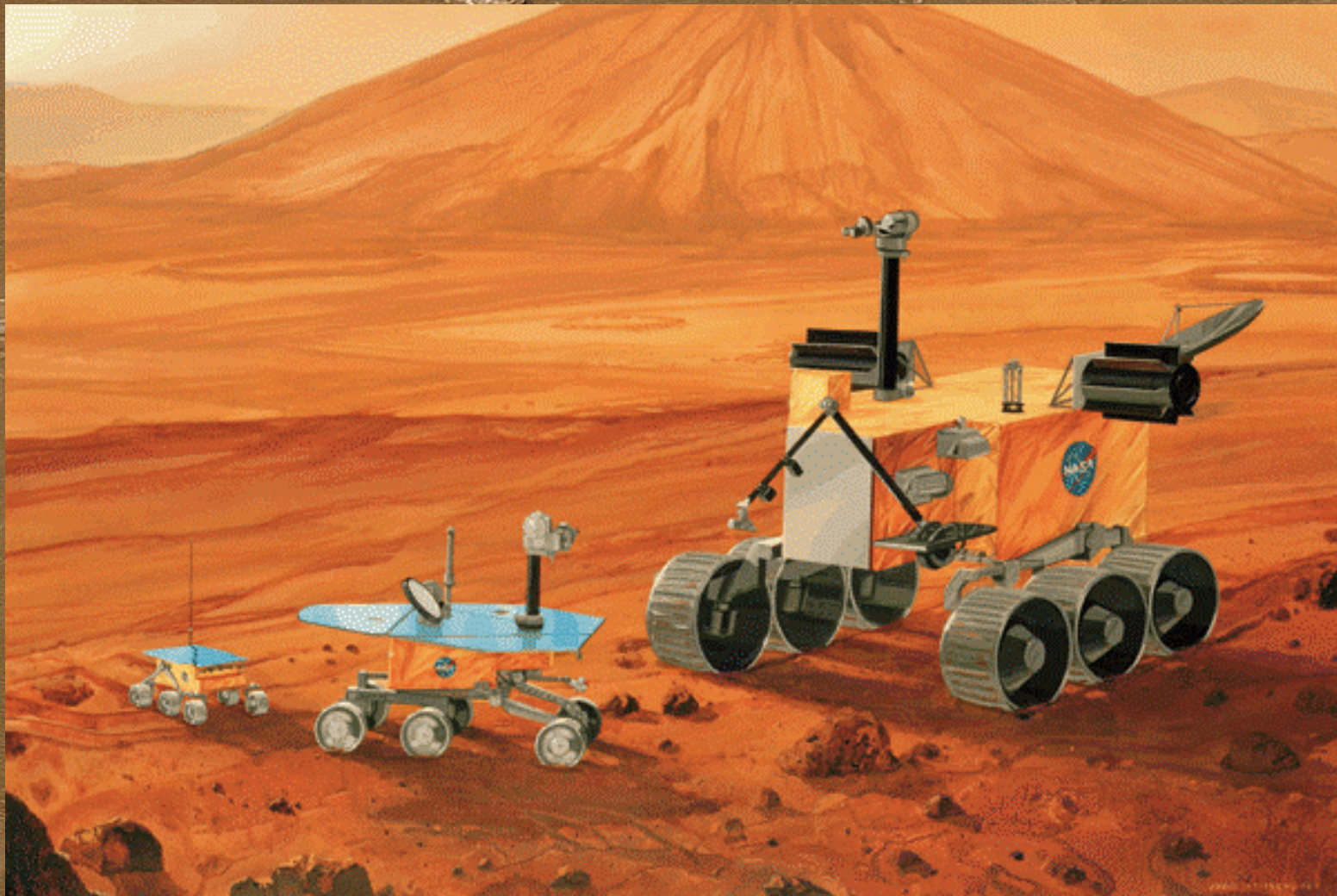
# Field Testing (cont.)



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# Mars 2007+



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# Inflatable Rover



- Light-weight, small package for launch, wheels expand on landing
- Large wheels allow the rover to go right over large obstacles and the travel at higher speeds,  $\sim 1\text{m/s}$  (2.2 mph)

# Scorpion Robot



- Biologically-inspired robotics
- Excellent mobility in rocky terrain
- Small, light-weight
- Could be carried by a larger robot

# Human Exploration



- Robots will act as aides for humans exploring other planets
- Rover roles for exploration with humans:
  - Scouts
  - Pack mules
  - Rescuers

